Artworks displayed in museums come from a variety of origins. Consequently, it is impossible to reproduce the design elements from their original settings and still maintain a coherent display in a new museum environment. Lighting, however, can subtly tie together an arrangement of works of art with diverse provenances. Furthermore, for museum-goers who wish to examine closely an artist's technical execution and style, light that is carefully balanced for each picture is required to render these elements visible. Proper lighting will optimize the viewer's ability to see nuances of artistic intent without distraction or eye fatigue and at the same time will minimize detriment to the physical state of the work. This brief essay will discuss varieties of lighting, how they affect our perception of paintings, and what constraints museums must operate under to provide illumination that will not damage the art.

The sun is the standard against which other light sources are measured. However, the illumination created by sunlight is very difficult to characterize in only one way since the sun's position in the sky and its interaction with the earth's atmosphere produce a wide range of light qualities. This range is contingent upon the dynamic relationships between the sun, the illuminated objects, and the viewer. Cloud cover is an additional factor that, when present, also modifies the quality of daylight. The standard, however, is based on the fact that the sun is a universal source of light. Fortunately, the sun emits a continuous band of radiation throughout the entire visible light spectrum. (“Visible light” is the term generally used to denote wavelengths perceptible to the human eye, although other species of animals may be able to discern light of wavelengths we cannot see.) Evidence of the continuous and broad range of colors in sunlight can be seen in rainbows.

In order for any color to be accurately registered by the eye it is necessary for light of that particular wavelength to be present in the light source. For instance, a green object seen in red light will appear...
2. Attic space above the Nineteenth-Century European Paintings and Sculpture Galleries. As direct sunlight comes through the skylight (upper left) it is diffused through translucent panels (center top) to maintain an even distribution of light in the galleries as the sun changes position. Supplemental fluorescent lights (left) are reflected off the panels into the gallery space below to supplement skylight when natural light is low. Spotlights (center bottom) are directed at the artworks below. (Note: The actual color of the fluorescent lamps is a warm yellow. Because a variety of light sources had to be accounted for, the film used for this photograph created an apparent green color shift in recording the fluorescent light.)

3. Manet Gallery in the exhibition space of the Nineteenth-Century European Paintings and Sculpture Galleries. Here Manet’s paintings are displayed on all four walls. Fortunately, from nearly every vantage point in the gallery glare has been eliminated so that the works can be compared instantly, without viewers having to reposition themselves.
gray, while in white light, which is actually composed of all colors, whether the source is natural or man-made, the object will appear green, as it can then reflect the green component of the light. Because of its continuous range of wavelengths, illumination from the sun provides unbiased color registration for all colors. Although the time of day, season, and type of weather alter natural light, the human eye, to a certain extent, can adapt to these changes and maintain the accurate perception of an object's color.

The most drastic alteration in sunlight's appearance is caused by molecules in the atmosphere that are capable of scattering the sun's radiation. These molecules can be anything from the gases that are the basis of Earth's atmosphere and those produced by living plants to various particles suspended in the air, such as microscopic dust and other matter. The only requisite for this phenomenon is that the molecules be within a certain size range, which even at the high end is still below the detection limits of the unaided human eye. The degree to which light is scattered depends upon its wavelength, with the shortest wavelength, that is, blue, undergoing the greatest scattering. Consequently, once the sun's rays enter Earth's atmosphere, the blue component will be scattered away from the straight line between the sun and the earth. (Leonardo da Vinci noted that there is often sufficient atmosphere between a viewer and distant mountains to make them appear bluer than closer mountains; see fig. 5.) Scattered blue light (called skylight) forms the color of Earth's sky, while the subtraction of this blue component from the direct light path makes the remaining sunlight

4. The visible light distribution of late-afternoon summer daylight, from readings taken from the rooftop of the Metropolitan; top, detector facing east (skylight); bottom, detector facing west (sunlight).

The background of each graph is the color of the portion of the sky from which the measurement was taken. As the background color suggests, the curve of the top figure (skylight) shows relatively more blue than yellow, while the bottom graph (sunlight) indicates slightly less blue, hence somewhat more yellow, light.

5. Opposite: Cosimo Roselli, Italian (Florentine), 1439–1507. Madonna and Child with Angels (detail). Tempera on wood, 33½ × 23 in. (85.1 × 58.4 cm). The Friedsam Collection, Bequest of Michael Friedsam, 1931 (32.100.84)

The blueness of distant hills was faithfully depicted by artists, as demonstrated in this detail, long before scientists could explain what caused the effect. Although Leonardo da Vinci (1452–1519) showed by experiment that water vapor scatters light, it was not until John William Strutt, third baron Rayleigh (1842–1919), a noted British physicist, demonstrated the relationship between wavelengths of light and scattering that this phenomenon was fully understood.
and the sun itself appear yellow. Together, sunlight and skylight constitute daylight (fig. 4).

At nearly any time of day it is possible to illuminate an object with a particular color of light, formed by sunlight or skylight, by adjusting how the object is positioned relative to the sun. For example, since in the northern hemisphere the sun travels through the southern sky, windows facing north will always transmit a consistent blue (often referred to as cool) skylight rather than sunlight. By contrast, illumination based upon sunlight (that is, from southern windows) will vary in color as the sun moves from east to west. Additionally, walls facing eastern exposures will appear warm in morning light and cool in afternoon light, while for those opposite western windows the reverse is true. It is perhaps artists' desire for consistent light that usually makes northern exposures the preferred natural light source for those in this hemisphere.

In galleries that use daylight as a source of illumination, a painting's appearance can alter throughout the day. The extent of this change is dependent upon the conditions mentioned above, on how natural light is directed by the architecture of the space, and on the artist's palette and painting technique. If the artist's palette is restricted to certain colors, what is referred to as a color trait or key becomes apparent; that is, the painting will have a predominantly cool or warm tone, or may show a preponderance of a specific individual color. The technique of juxtaposing colors can affect the color trait. For example, small highlights of warm or cool pigments adjoining a neutral white area will make the entire white passage appear, respectively, warmer or cooler. Illu-
In this painting La Tour was restricted to a warm palette since the candle and its mirror image are the sole illuminants for the scene. All of the elements in this picture, from the subject's skin tone and garments to the symbolic objects, contain small amounts of yellow, orange, or red pigments added to shift these elements to a warm tone. With his technique and palette, La Tour convinces the viewer that the light from the candle does not extend far beyond the boundaries of the frame and that there is no stray light from other sources.

In order to emphasize subtle colorations, regardless of whether or not the natural light of any particular moment supports them, properly colored supplemental lights can be directed on the painting. In this respect, the objective of gallery lighting, whether natural, artificial, or a mixture, is to provide sufficient color-match in the wavelengths from the light source that the tone of the painting as originally intended by the artist is always apparent.

Incandescent lights produce light based on the same fundamental principles as sunlight. Elements within the bulb, or lamp, are heated to a high enough temperature that they begin to glow—the higher the temperature the bluer, or cooler, the appearance of the light. This concept is well known to photographers, who often have to know the color "temperature" of a subject's illumination so that they can use the corresponding film. A low color temperature implies a warm, or yellow, light, while a high temperature indicates a whiter light. Although
incandescent sources are good at mimicking direct sunlight they are still incapable of re-creating the bluish cast of skylight because of the insufficient distance, and hence atmospheric scattering, between the source and the viewer. Tungsten lamps filled with inert gaseous halogens (tungsten-halogen), which can burn efficiently at higher temperatures than conventional light bulbs, produce the whitest light available from incandescent sources; however, even these lamps cannot reproduce blue, northern skylight. If desired, it is possible to vary the appearance of incandescent light by transmitting it through blue-tinted filters or by reflecting it off walls that have a cool tint.

Fluorescent lights create illumination on a principle different from that of either sunlight or incandescent sources. The coatings inside fluorescent lamps absorb high-energy ultraviolet (UV) radiation from mercury vapor inside the tube and emit visible light at discrete wavelengths. In fluorescent light these discrete wavelength emissions correspond to different colors of visible light. The inner coating can be modified so that the resulting colors can add up to a light that appears similar to different types of daylight (fig. 8). For instance, there are several fluorescent tubes available that give off a moderately low-wattage, cool, northern or warm, southern type of light.

7. Johannes Vermeer, Dutch, 1632–1675. Young Woman with a Water Jug, early 1660s. Oil on canvas, 18 x 16 in. (45.7 x 40.6 cm). Gift of Henry G. Marquand, 1889 (89.15.21)

In this painting Vermeer uses a predominantly cool palette. The skylight from the window cools the highlights in the young woman's skin. Her hood and collar have a crispness that was achieved by adding a small amount of blue pigment to the white garment: a cool blue light is also transmitted through the hood to provide a faint outline of the back of her head. The surfaces of the silver tray and jug that face the window or the reflective blue fabric are clearly shifted toward blue and the blue geometric pattern of the oriental rug is so intense it is difficult for the viewer to focus on it and the adjacent orange at the same time.
The ability of fluorescent lights to render colors correctly is a different issue. For example, if the intrinsic color of an object or pigment is poorly represented in the light source, that color will appear muted. Conversely, if the light emits an overabundance of that wavelength, the color will be amplified. This is especially a problem for red colors that are often poorly represented in the light source. To render a color accurately, light of that specific range must be present in correct proportion relative to the overall illumination. Because of the gaps in the wavelengths produced by fluorescence, accurate color rendering cannot always be achieved. Despite its limitations as a sole illuminant, however, fluorescent light can be used as an ambient source in the viewer’s peripheral vision to suggest satisfactorily either a northern or southern light.

In addition to using lighting that supports the tone of a painting, it is necessary for museums to employ lighting appropriate to the needs of works that contain fugitive or unstable materials. For example, the yellowing of some varnishes is slowed considerably when they are no longer exposed to UV radiation. Fortunately, properly filtered UV radiation is nearly imperceptible to the human eye and consequently it is general practice to eliminate it from the gallery setting. However, even when UV is filtered out, fugitive dyes may be only marginally buffered from damage, since these dyes will fade after exposure to a critical dosage of visible light. By cutting the illumination intensity or exposure to visible light in half, in principle one doubles the lifetime for that particular dye’s color. Paintings with fugitive materials are normally exhibited separately in galleries that have absolute minimal visible light levels and are usually displayed on a rotating basis. Distinguishing un-
stable materials from those that are lightfast requires either knowledge of the artist’s palette or technical examination.

Gallery lighting usually consists of a combination of direct and diffused light. These two sources contribute to the light level at the surface of the painting. Paintings illuminated with excessive light, aside from the issue of fading, can be just as difficult to decipher as paintings that have insufficient light. Paintings illuminated with too much direct (spot) light, particularly varnished ones, from some vantage points may reflect specular “hot spots” of the light source rather than the image of the painting. This can be remedied by moving the light source so that the glossy reflection is directed away from the viewer’s line of sight. When diffused light is excessive or improperly located, it has the tendency to cause certain paintings to lack depth and appear washed out or gray. Again, varnished paintings suffer the most dramatic effects when this illumination is not rectified; because they have a smooth surface they will reflect light primarily from the top surface of the varnish and not from the pigmented depth of the paint layer as they should. This condition may be difficult to perceive because the lack of darkness (or saturation) is even across the entire surface, the diffuse light causing a white sheen over the whole, and therefore the work could be mistakenly thought to have been painted with lighter colors. However, when the lighting is properly adjusted, the depth of the painting is immediately apparent through subtle contrasts, most easily noted in darker passages.

Ideally, therefore, a gallery should contain two types of lighting. There should be an over-all scheme that settles on an illumination that underscores the common traits found within an arrangement of paintings. Once this base has been established individual paintings, where necessary, should receive supplemental lighting that enlivens aspects otherwise imperceptible to the viewer. It is also necessary to use illumination with minimal or no UV at levels beneath a visible light threshold considered safe for the media on display.

Especially successful lighting schemes can be seen in several galleries throughout the Museum. For example, in the Robert Lehman Collection, in the gallery where Goya’s The Countess of Altamira and Her Daughter and other paintings are displayed, the works are mostly rendered in a cool key, and the lighting is designed to reflect back to the viewer from cool gray walls. Although the room is illuminated by both warm and cool light, the gray walls absorb the warm components and allow the cooler illumination to envelop the paintings, while the warm (in this case, fluorescent) light is only apparent at the ceiling. One can peruse passages in these paintings without any significant distraction from warm light reflected by the wall. This use of warm and cool lighting creates an agreeable interior space. The warm tone at the ceiling establishes it as a horizontal plane clearly distinguished from the vertical (wall) surfaces, without which differentiation the room would appear flat and less inviting. In the adjoining gallery, where fifteenth-century Italian paintings are on display, the opposite lighting configuration is required due to the warm tone of these pictures. There cool light is retained at the ceiling and warm light, reflected from the red velvet walls, surrounds the paintings (fig. 9). The newly installed Nineteenth-Century European Paintings and Sculpture Galleries also offer excellent examples of lighting used to optimize enjoyment of the works of art (see fig. 3). Here the Museum’s lighting designer, Zack Zanolli, has satisfied both curatorial and conservation needs. The relatively shallow attic space required translucent diffusers to harness the arc of sunlight throughout the day and redirect it consistently downward. By using such panels Zanolli was able to create a dynamic natural light that concentrates on the floor rather than the walls, where raking light would cause disturbing glare on the paintings at certain times of day. During the construction process, materials with the best UV-absorbing qualities were selected. The result is an exhibition space that provides vistas of glare-free paintings in galleries where harmful UV radiation has been effectively eliminated. Clearly sensitivity to these details fosters an environment that welcomes viewers and helps create an atmosphere where they are encouraged to look at paintings in a relaxed manner.

With all these considerations in mind, museum specialists decode, as it were, the specific lighting needs encrypted within each artwork. For the large and diverse collections of the Metropolitan there are many unique lighting solutions. Perhaps the greatest challenge is to specify changes in lighting from gallery to gallery so that the variations are only briefly noted, if at all. By achieving this goal, museumgoers' attention will remain focused on the collection rather than the installation.